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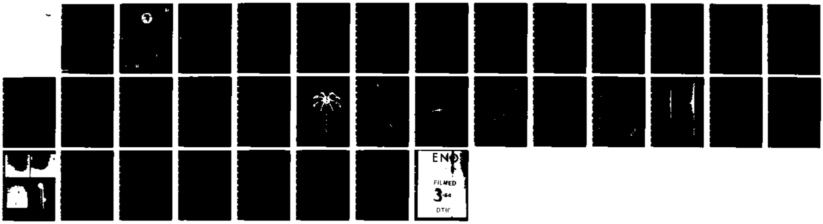

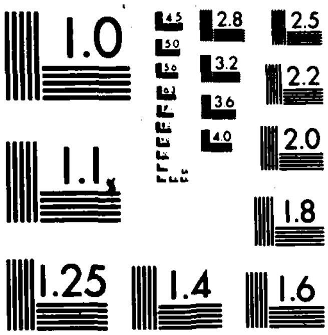

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LIGHTNING STRIKE ELIMINATION, THE STORY OF DISSIPATION ARRAY SYSTEMS

ROY B. CARPENTER, JR.

DECEMBER 1982

REPORT NO. LEA-82-6

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INTRODUCTION

Scope and Objectives

This paper has been written by Roy B. Carpenter, Jr., founder of Lightning Elimination Associates, Inc. (LEA) and developer of the Dissipation Array System of lightning protection.

The Dissipation Array System (DAS) is protected by U. S. Patent Number 4180698 and has been extended to cover the DAS in many foreign countries. The DAS is wholly owned by LEA and may not be reproduced by anyone or any government agency unless licensed by LEA.

This paper has been prepared to provide the technical community and potential customers with a working knowledge of the DAS as a concept and to provide sufficient reliability information to develop confidence in DAS applications. This paper summarizes the lightning hazard as defined by others, evaluates the protection concepts, provides the theory behind the DAS and describes a few practical concepts to illustrate its use and flexibility.

It should be understood at the outset that neither LEA nor the writer are claiming to be experts in the field of atmospherics physics or the lightning phenomena. Rather, we are considered experts in the field of lightning protection and protection against its related phenomena. In consonance with this the writer has extracted data from the writings of a great number of recognized experts in the field of atmospheric physics to help define the lightning hazard. Some of the more important works are listed in the bibliography.

Background

Since June of 1971 LEA and its founder have been actively marketing a system guaranteed to prevent lightning strikes to the protected area. This system is called the Dissipation Array System because of the operational concept by which it performs that function. Since the founding of LEA many hundreds of systems have been installed in different parts of the world. Most have been in areas where there is a high lightning stroke hazard and where prior site history reveals significant losses due to lightning activity. History subsequent to the DAS installation shows the systems have prevented strikes to the protected areas in all but the earliest installations.

The DAS was developed in an unconventional manner; that is, through use of an empirical approach consisting of two somewhat conventional stages, lab tests and field tests, with one variation; the field tests were at actual customer installations. This may seem strange, however two factors mitigate this approach. Field conditions can be neither simulated nor controlled, and the customers selected had an acute problem for which no alternate, conventional solution was effective. Some case histories of these early applications are documented in this paper.

The lab tests were conducted during 1971 and early 1972, and provided much of the design data for the dissipator assembly. Some field trials were conducted independently to obtain the necessary extrapolation or scaling factors. During this period demonstration systems were installed on customer facilities under a cost sharing program; one at KHOF-TV, Sunrise Mountain, California, and one in Running Springs, California for Continental Telephone. Both sites had a prior history of severe damage from lightning and to this writing, over ten years later, neither have suffered damage or recorded a strike to their facility since the DAS was installed.

Although lab tests provided some data and the demonstration sites were resounding successes, there yet remained the need for configuration and/or application design data. This could only come by practical applications of theoretical studies, so the next few years (about three) involved a series of customer installations using different development configurations. Many were successful, a few were not. Subsequently, most of the failures were modified to correct any deficiencies. Continuing evaluations of systems and configuration performance resulted in several design alterations.

System Definition

The Dissipation Array System is designed to prevent lightning strikes to a specified area which includes both the protected facility and the protector. The potential in the protected area is reduced with respect to both the clouds and the surrounding site. The induced charge in the protected area is also reduced and the overall charge generated by the storm is reduced to some degree, but not significantly unless there are many Arrays in the same area.

Arrays individually produce significant current flows only when subjected to the intense fields preceeding the formation of a lightning strike within the immediate area of concern.

Atmospheric Electricity and the Lightning Phenomenon

Atmospheric electricity is the general phenomenon, lightning is one of its manifestations. Little is known for sure with respect to the creating forces. Many men have devoted their lives to studying this phenomenon and there are some very good books on the subject, a book by Dr. A. Chalmers being one of the best.[1] The personnel at LEA have developed an expertise in identifying the problems created by lightning and in finding a solution. To deal with lightning and its related phenomena it is necessary to understand the situation created by atmospheric electricity.[2] The available literature [1-5] is quite helpful. Following is a summary as it applies to protection requirements:

The thunderheads are electrically charged bodies suspended in an atmosphere that may be considered at best a poor conductor. During a storm situation charge separation will continue to build up within the cloud until the potential within the cloud and the related field strength beneath it reaches a point where the insulating quality of the air gap is no longer effective and breakdown takes place. The specific breakdown point varies with atmospheric conditions. The potential at the base of the cloud is generally assumed to be 10^8 volts and the resulting electrostatic field about 10 Kv per meter of elevation above earth. The charging action (or charge separation) within the storm cell usually leaves the base of the cloud with a strong negative charge, but in about ten percent of the cases the opposite seems true. This resulting charge induces a similar charge of opposite potential into the earth concentrated at its surface just under the cloud, of the same size and shape as the cloud. As structures intervene between the earth and the cells they are likewise charged. However, the field around these is higher since they short out a portion of the separating air space. The ultimate result can be a triggered strike, either because of the lesser air space or because the structure was high enough to start an upward moving leader. (See Figure 1).

Thunderstorms are generally of two types; convection storms which occur locally and are of relatively short duration, and frontal storms which extend over greater areas and may continue for several hours. Storms of the convection type account for the majority of annual thunderstorm days in North America, yet experience indicates they produce less plant damage than thunderstorms of the frontal type.

The formation of convection thunderstorms tends to depend on local meteorological and topographical conditions. They predominate during the summer months, since they are caused by local heating of the air near the earth. Convection storms are non-regenerative in nature because the accompanying rain soon cools the earth and dissipates their source of energy.

Frontal thunderstorms result from the meeting of a warm, moist front and a cold front which may extend for several hundred miles. This exposes large areas to particularly severe and destructive lightning discharges. Such storms are regenerative in nature because air masses continue to move into the area and maintain for hours the turbulence necessary to the thunderstorm process. Observations indicate that the magnitude and especially the incidence of strokes to ground is substantially greater in frontal storms than in convection storms. Conditions in the southeastern part of the United States and in some of the midwestern states are particularly conducive to frontal storms. These storms tend to predominate in the spring and early summer, but are occasionally experienced during the winter. Such mid-winter storms can be particularly destructive when they occur in conjunction with snow. The typical range of thunderstorm cloud sizes is illustrated by Figure 2.

Figure 1

Charged Cloud Influence On Surface Facilities

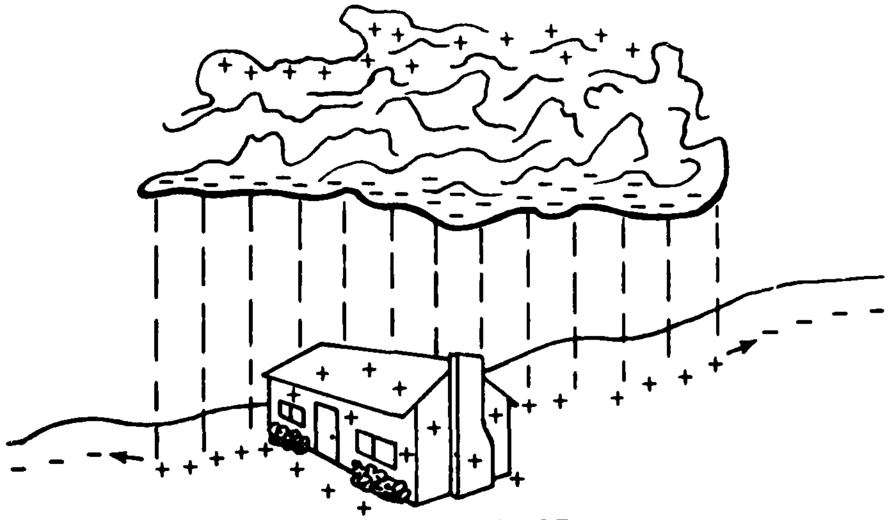
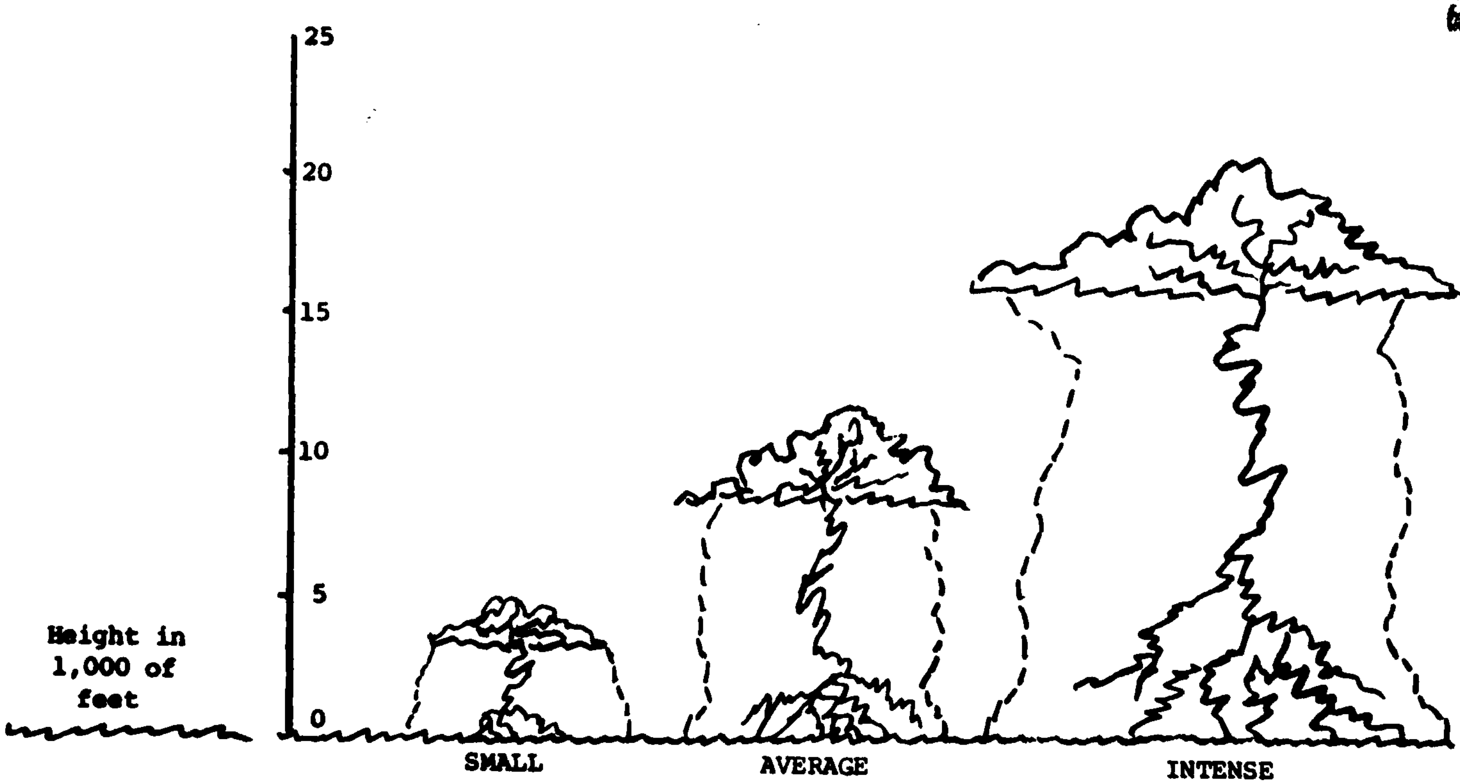


Figure 2, The Range in Thunderstorm Cloud Sizes



LIGHTNING PROTECTION CONSIDERATIONS

The Lightning Strike Hazard

The lightning strike hazard for any given facility is a statistical function that is related to a number of factors associated with that facility and its location. These factors include size, geographical location, type and character of the facility, and of course, the character of the lightning stroke itself. For example:

The Keraunic Number determines the system exposure rate in that the higher the number the greater the stroke activity encountered in that area. As Figure 3 indicates, in the United States this number varies from a low of 1 to over 100. In other parts of the world it is as high as 260[6]. There is an average of 30 storm days per year across the United States, however, many strokes do occur in a single storm. Studies have shown that for an average area within the U.S.A. there can be between eight and eleven strokes per year to each square mile within this area. Using central Florida as a reference state, hazard increased to between 28 and 37 strikes per square mile per year.

The structural character, such as height, shape, size and orientation influences the hazard. For example, as illustrated by Figure 4, higher structures tend to collect the strokes from the surrounding area. It is evident that the higher the structure the more strokes it will collect. However, it may not be so evident that high structures will also trigger strokes that would not have occurred otherwise. Further, since storm clouds tend to travel at specific heights, with their base at from five to ten thousand feet, structures in mountainous areas tend to trigger lightning even more readily.

The system exposure factor is a function of the size of the system as well as the isokeraunic level of the area. It is obvious that the larger the area the greater the stroke potential. It also follows that the longer a transmission line the more strokes it can expect. For example, consider a 50 mile stretch of transmission line in central Florida. According to the IEEE Subcommittee on Lightning[7] there should be about 1500 strokes to the line, i.e., total to the static wire and phase conductors. Two Hundred, Twenty-five of these will exceed 80,000 amperes, all in just one year.

Lightning stroke character is a statistical function that varies significantly over a wide range of values. The more important parameters include:

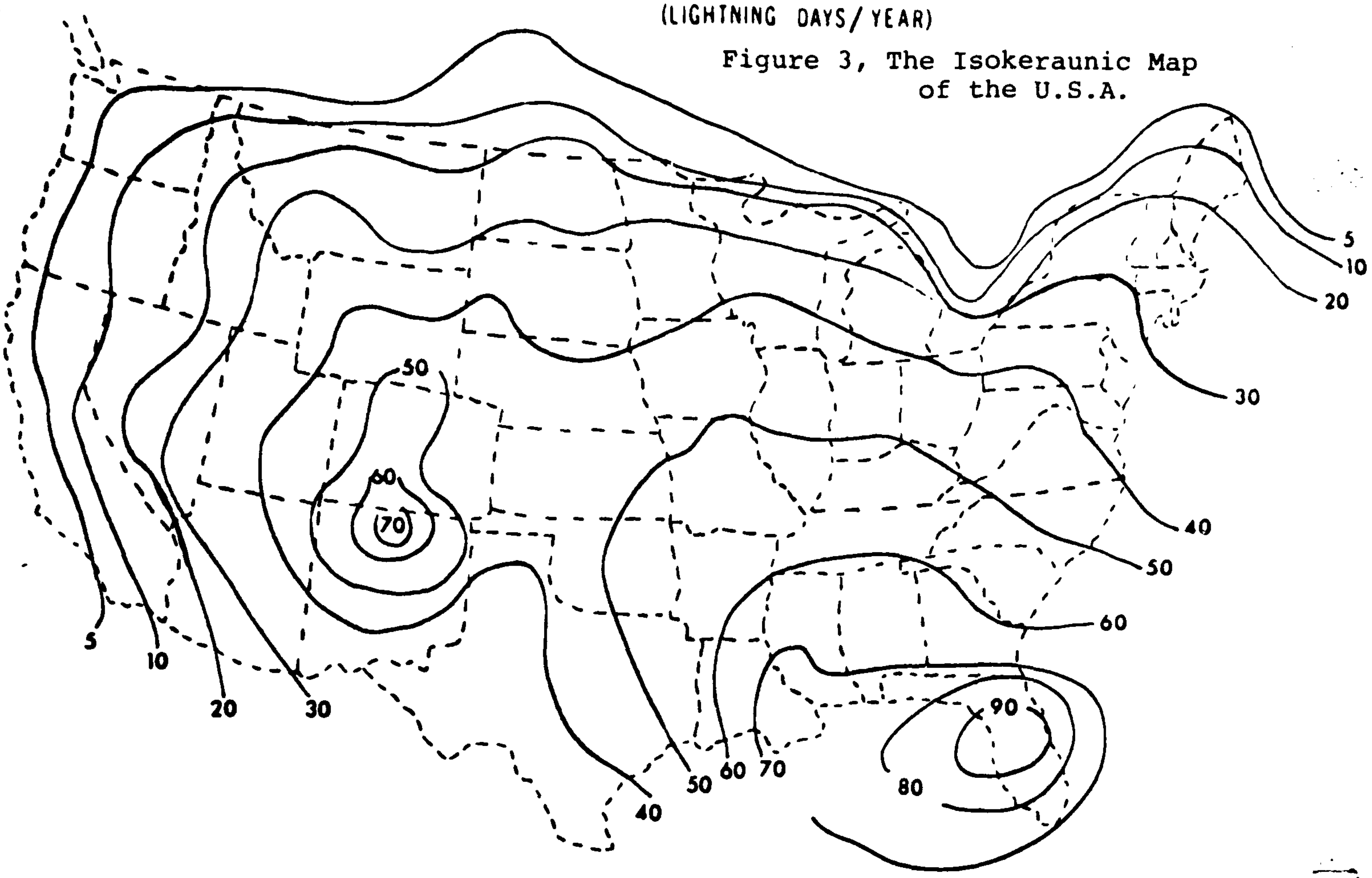


Figure 3, The Isokeraunic Map of the U.S.A.

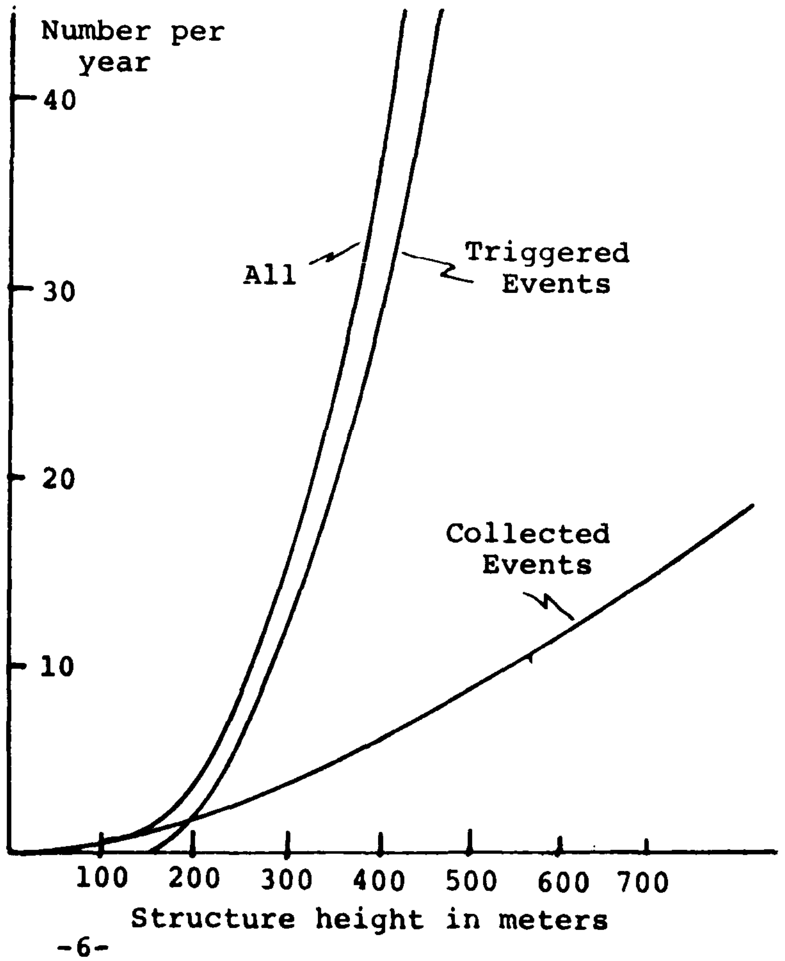


Figure 4, Lightning Incidents to Tall Structures

Total Charge Transferred	- 2 to 200 coulombs
Peak Currents Achieved	- 200 to 400,000 amperes
Time (duration) to half value	- 10 to 250 microseconds/stroke
Current Rise time to 90%	- A few nanoseconds to 30 microseconds
Velocity of propagation	- 1 to 21 x 10^6 meters per second
Time between strokes, in one flash*	- 3 to 100 milliseconds
Number of strokes per flash*	- 1 to 26 (average <4)

*A flash is defined as the ionized channel resulting from the lightning discharge; it may contain from 1 to 26 or more strokes before it clears.

Dealing with a Direct Lightning Strike

Ever since there has been any thought given to lightning protection the vast majority of that thought has been based on the premise that lightning is "an act of God" and as such should not , and indeed cannot, be influenced by man. By virtue of the same reasoning men were also told they could not fly, go to the moon, etc. If this premise is to form the basis of our design practice then the designs will be based on the diversionary principle which forms the basis of lightning rod systems and technology will be limited by the resulting constraints and performance limitations. This principle is a remedial form of protection that treats the symptoms rather than the cause.

To provide a successful remedial design the following factors must be taken into account: the probability of capturing the stroke; the ability to divert the energy by and away from the protected system; and, the grounding resistance of the ground plane available.

To illustrate, consider a lightning rod on a 100 meter tower used for FM broadcasting. Based on the usual installation criteria, the lightning rod has no more than 0.95 probability of capturing the strike. At least five percent of the time the stroke will reach one of the antenna elements. If the captured stroke is of average magnitude 20,000 amperes must be carried to the ground plane within a few microseconds. The effective surge impedance of the down-conductor is in the order of from 100 to 600 ohms, and the mutual inductance of the antenna coax could be of a related order. If the grounding resistance were only ten ohms, as much as 200,000 volts could be developed across it. Further, the surge impedance of the grounding system must be considered. A simple resistance test does not properly evaluate the grounding capability.

Dealing with the Cause

If the problems inherent with lightning rods are to be overcome the stroke must be eliminated from or near the area of concern. A system that deals with the cause must be based on the premise that lightning can be eliminated within the area, where elimination connotes the prevention of stroke formation to both the protector and the protected; where the total number of strokes produced by the storm is reduced proportionally.

The cause is atmospheric electricity, and, specifically, the build-up of the potential between a cloud and the earth's surface to the point where the air space between is no longer an insulator. To effect a cure (elimination or prevention) the protective system must prevent the breakdown of air or limit the potential between the site of concern and the cloud cells to a safe value. The Dissipation Array System does just that, not necessarily by significantly affecting the cloud charge, but rather by reducing the difference in potential to below stroke potential.

THE DISSIPATION ARRAY SYSTEM

Theory of Operation

The Dissipation Array System (DAS) has been designed to prevent a lightning strike to both the protected area and the Array itself; nothing more nor less. It is a misconception to infer that an Array is designed to dissipate a storm, or even a single cloud. Although in theory it is true that any ion current dispersed into the atmosphere will reduce the overall charge, that is not necessarily the design objective of the DAS.

To prevent a lightning strike to a given area a system must be able to reduce the potential between that site and the cloud cells, such that it is not high enough for a stroke to form within that area. Protection may also be thought of in terms of dealing with the charge. The protective system must release, or leak off, the charge induced by the storm in the area of concern to a level where a lightning stroke is impractical. Charge induction comes about because of the strong field created by the storm and the insulating quality of the intervening air space as shown by Figure 1. Charge reduction may be accomplished by taking advantage of this field and the "point discharge" principle. Since atmospheric scientists tell us[1] that most of the storm's energy (over 90%) is dissipated through what is called natural dissipation, a multi-point dissipator is simply an extension of that phenomenon through use of a more efficient medium. Natural dissipation is the result of ionization produced by trees, grass, fences and other similar natural or man-made objects that are exposed to the field created by storm clouds.

The point discharge phenomenon was identified over a hundred years ago. At that time it was found that a sharp point immersed in a strong electrostatic field, where its potential was elevated above 10,000 volts with respect to its surroundings, would leak off electrons by ionizing the adjacent air molecules. A typical laboratory schematic is shown on Figure 5. It can also be shown that as the potential is increased the ion current increases exponentially. Given that the foregoing is true and that natural dissipation takes place as a regular event during storm conditions, it is evident that the point discharge phenomenon can be reproduced in the field and significantly enhanced through use of very efficient dissipators. R. H. Golde, in an article written for the Franklin Institute[8], verifies this premise by stating, "6000 such conductors (referring to pointed lightning rods) would be required over an area of, say, half a square mile to prevent one lightning flash".

The Dissipation Array System is based on the premise that the point discharge phenomenon can be enhanced and will provide a mechanism to significantly reduce the induced charge in a given area, thereby reducing the potential difference between that area and its surroundings, as well as the charging cloud cell. The DAS is composed of three basic elements: the dissipator (or ionizer), a Ground Current Collector (GCC), and, the service wires, as illustrated by Figure 6.

In contrast to a single-pointed lightning rod, the dissipator is a multi-point device designed to efficiently produce ions from many points simultaneously. The single point lightning rod is usually a more efficient ionizer than the higher point density dissipator at low electrostatic potentials because of the so called "interference phenomenon" between adjacent points. However, as the storm increases in strength and the electrostatic field increases, the single point will create upward going streamers which tend to encourage a strike to that point. In contrast, the multi-point dissipator starts the ionization process at a somewhat higher potential, but as the potential increases, the ionization current increases, exponentially. Since these ions are spread over a large area no breakdown can occur, but rather in extreme situations a luminous cloud of ions is produced causing a momentary glow of the Array and a sudden burst of current flow. This only occurs under an intense storm and/or when lightning would otherwise have struck at or near the site. The dissipator assembly is very sensitive to a number of design parameters, some of which can be reduced to formulation and some of which cannot. These factors include size, shape, elevation, point shape, point height above the Array face, point spacing, range in wind velocity and the character and relationship of the surroundings.

The Ground Current Collector (GCC) provides the source of charge to keep the ion current flowing through the Array. The GCC is designed to provide an electrically isolated or floating ground subsystem for the protected area with respect to the earth, or mother earth itself. Since the induced charge created by the storm is at the earth's surface, that portion of the earth's surface containing the facilities to be protected is usually surrounded with the GCC as illustrated by Figure 7. The GCC is composed of the Ground Current Collector wire buried to a depth of about 25 centimeters and ground rods about one meter long connected with the GCC wire and spaced at intervals of about ten meters. The enclosed area is often integrated by a net of cross conductors which also connect surface structures and public utilities with the system. The cumulative resultant is an electrically integrated island surrounded by and isolated from the less conductive soil. The short ground rods give the island enough depth to assure collection of any charge induced within the area of concern, thus isolating it from its less conductive surroundings. It functions as follows: as the charge moves into the area it first interfaces with the GCC which provides a preferred path for the charge from this point of interface to the dissipator or ionizer assembly by means of the service wires, thus essentially bypassing the protected area. As schematically portrayed in Figure 8, the current flow thus created through the surrounding surface soil causes a small voltage drop across that soil resistance such that the electrically isolated island established by the GCC is reduced to a lower potential than its surroundings.

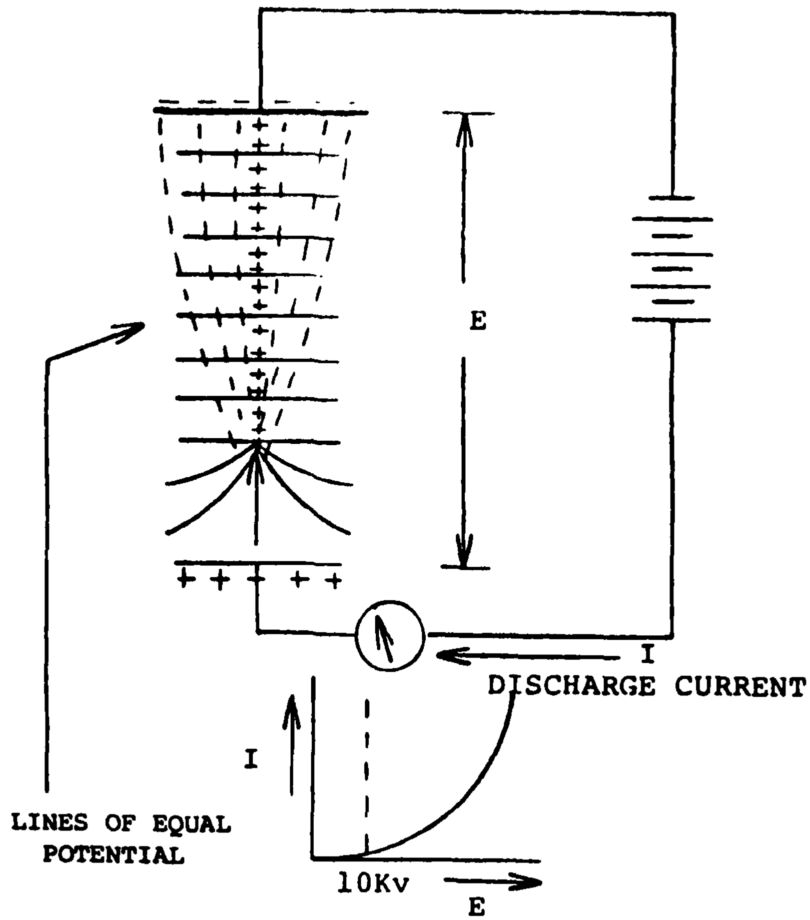


Figure 5, The Point Discharge Phenomenon

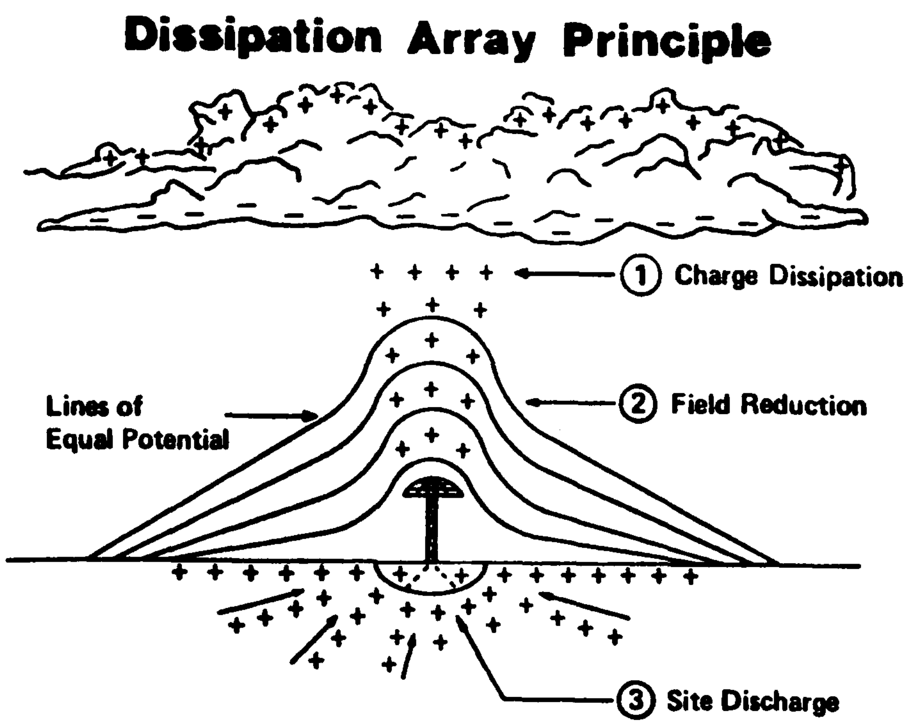


Figure 6

The service wires function to provide a direct, low-resistance path from the GCC to the ionizer and to integrate the protected facility and its grounded points. In contrast to a lightning rod system, these wires carry low current levels over the shortest path possible and are selected more for structural integrity than for current carrying capacity, the maximum current flow being in the milliampere range (measurements indicate less than ½ ampere at maximum).

The significance of the electrically isolated island and ionic current flow from it is summarized in the following:

(1) The current flow from the ionizer through the air space above it reduces the potential of the protected site and facility with respect to its surroundings by draining a part of the charge from the protected area. The resulting impact is over-emphasized by Figure 9.

(2) The presence of free ions or space charge between the protected facility and the cloud structure forms a type of faraday shield between them, thus providing some isolation for the facility from much of the storm influence.

(3) The cloud potential is reduced to some degree by those ions reaching them, thus neutralizing a small portion of its charge and augmenting the natural dissipation provided by both man and nature.

Design Considerations

The DAS is not merely a single configuration, but a multiplicity of shapes and sizes. Each system must be engineered to fit the facility to be protected and often the site as well.

Many factors influence the DAS design, including size of the area, height of structures, shape of structures, prevailing wind conditions, soil type, functional requirements and constraints of the facility to be protected, and finally, the protective mode to be used for each specific problem. The protective mode factor involves:

Selection between area coverage vs unit-by-unit coverage;
Selection between grouped coverage vs total coverage; and,
Selection between coverage from above vs coverage from below.

Other factors are of less significance, but site or system peculiarities can change their relative significance.

Some Practical Considerations

Caution: The Dissipation Array System is protected under U.S.Patent laws, Serial No. 4180698. LEA will prosecute anyone who infringes on this patent because of the potential impact on our reputation of failed systems.

Ground Current Collector Function

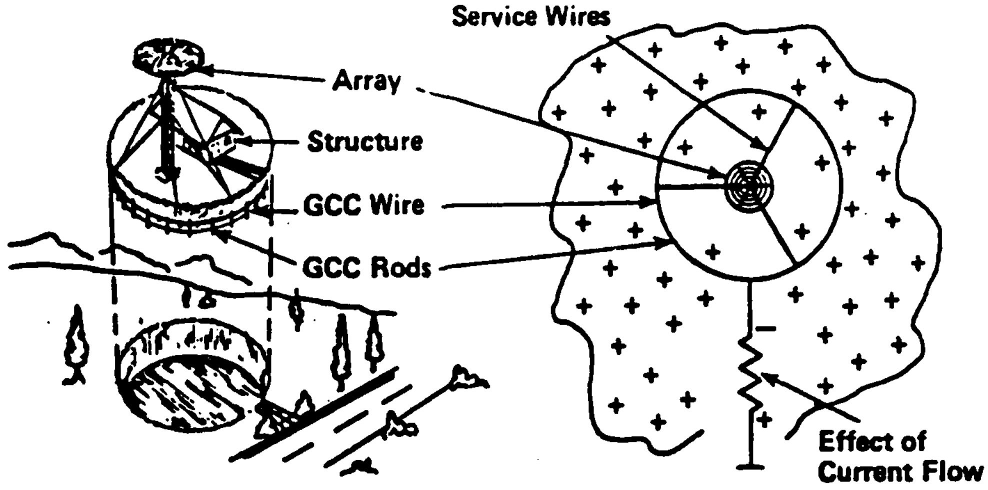


Figure 7, The Ground Current Collector; Figure 8, Schematic

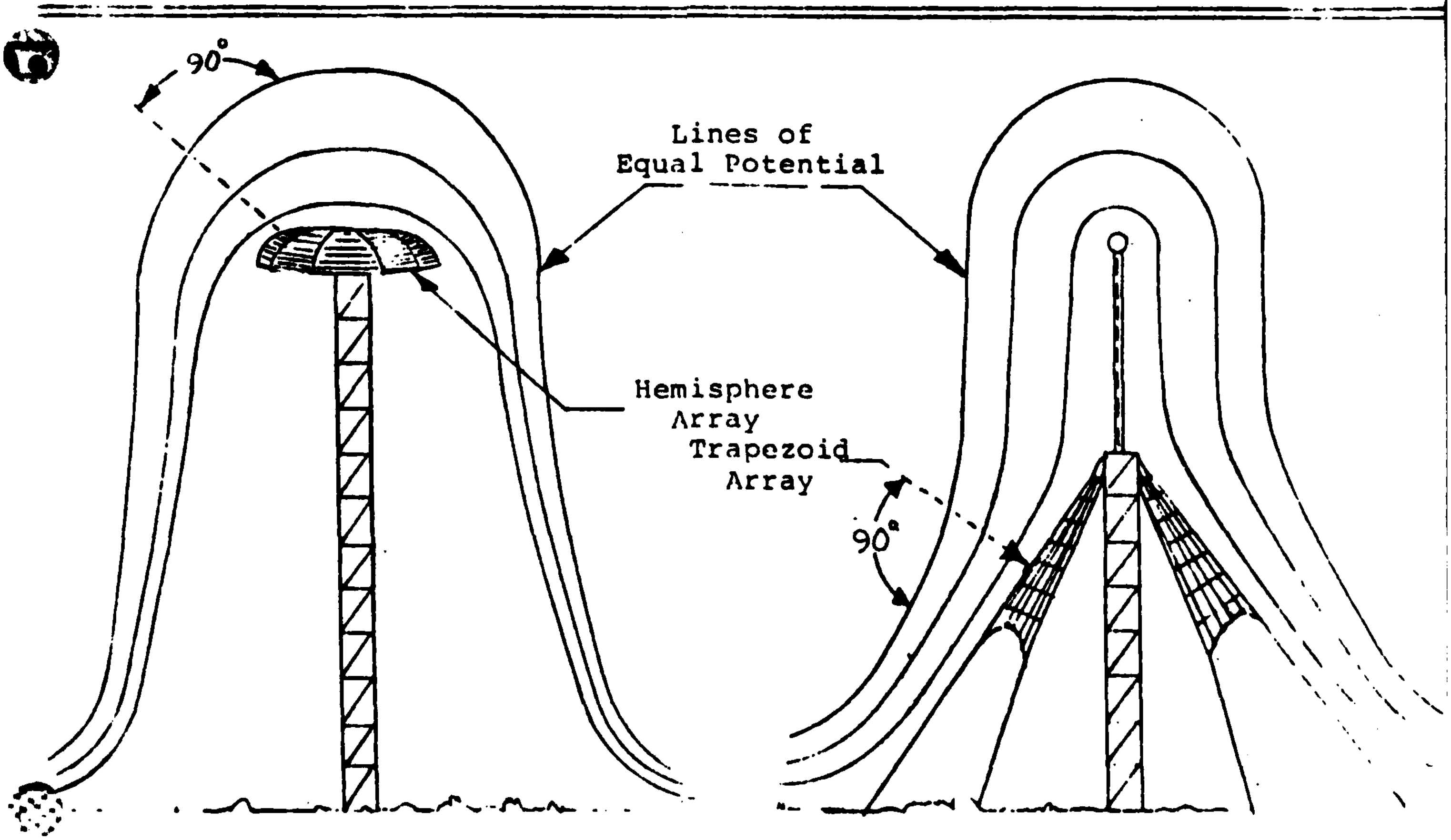


Figure 9, The Equipotential Line Formation over a Site Protected by A Dissipation Array System

The Dissipation Array System is a concept for which there are many potential designs, perhaps as many as there are variations in the type of facilities to be protected. However, there are a few basic design configurations that are used repeatedly, the dimensions for which vary significantly with the facility to be protected. Some of the more useful configurations include:

The Hemisphere Array as illustrated by Figure 10 is usually used for the protection of towers that range in heights up to about 100 meters. It may be used in conjunction with a tower or elevated structure to protect facilities such as substations, tank farms, watertowers, radar installations, launch pads, etc.

This Array is shaped similar to a segment of a hemisphere where the top is at 90 degrees with respect to the tower or supporting structure and the sides are parallel to that structure, thereby making a full 90 degree arc with the dissipating medium. The size can vary in overall diameter from about 1.6 meters to 6.0 meters or more.

The Trapezoid Array as illustrated by Figure 11 is used for the protection of very high towers, for those towers considered vulnerable to side strikes, and/or, where there must be components above the Array. Examples include television and FM Radio Transmitting facilities.

This Array is designed to attach directly to the tower as near to its top as possible. The lower end can either be attached to the existing upper guys or it may be anchored to the existing tower anchors. This Array has the advantage of not adding any appreciable wind load to the tower and very little static load.

This Array is trapezoidal in shape, being larger at the base than at the top by factors of up to 6 to 1. The specific size varies with such factors as tower height, face width, function, surrounding topography and interference constraints. This form of Array does not need to be the uppermost hardware on the tower. These Arrays have been successfully used on towers approaching 350 meters in height with antenna extending 30 meters above the Array.

The Conic Array as illustrated by Figure 12 in one application may be used in conjunction with many structural shapes, but has significant esthetic drawbacks. It is supported in the center by a pole or tower and each dissipating wire is brought down separately to ground, resembling a May Pole. The Array's conic angle may be varied over a wide degree, depending on the facility to be protected. This is probably the least costly Array to produce.

The Building Array is to be used in place of lightning rods to protect any type of building. It must be designed to fit the specific building. Figure 13 illustrates a particular application for a simple house or building. The location of the dissipating wire is important as it must be deployed so as to assure interaction with the lines of equal potential as they form on the roof or uppermost part of the structure. This Array is constructed on site.

Figure 10, A Typical Hemisphere Array Installation

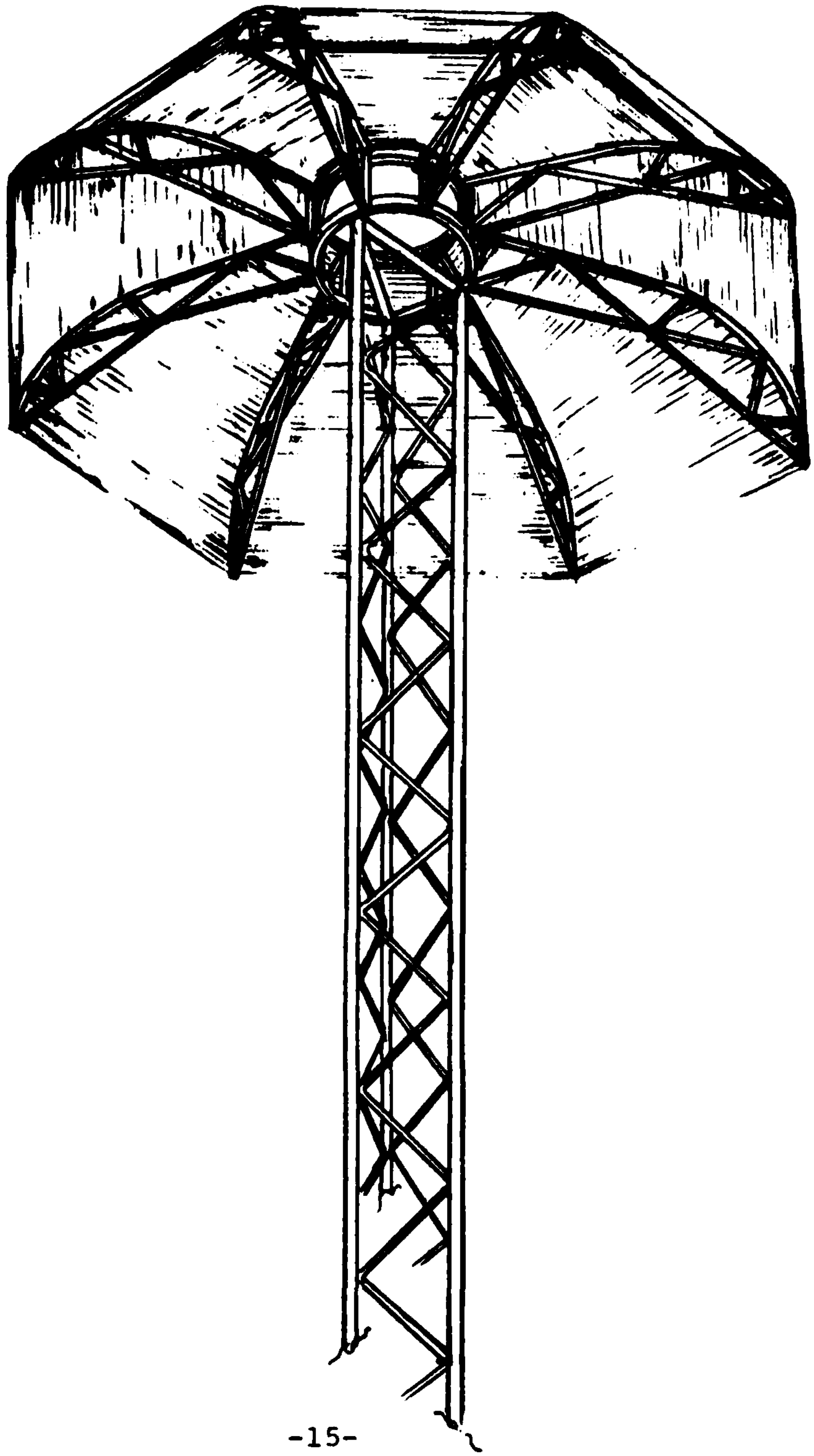


Figure 11, A Typical Trapezoid Array Installation

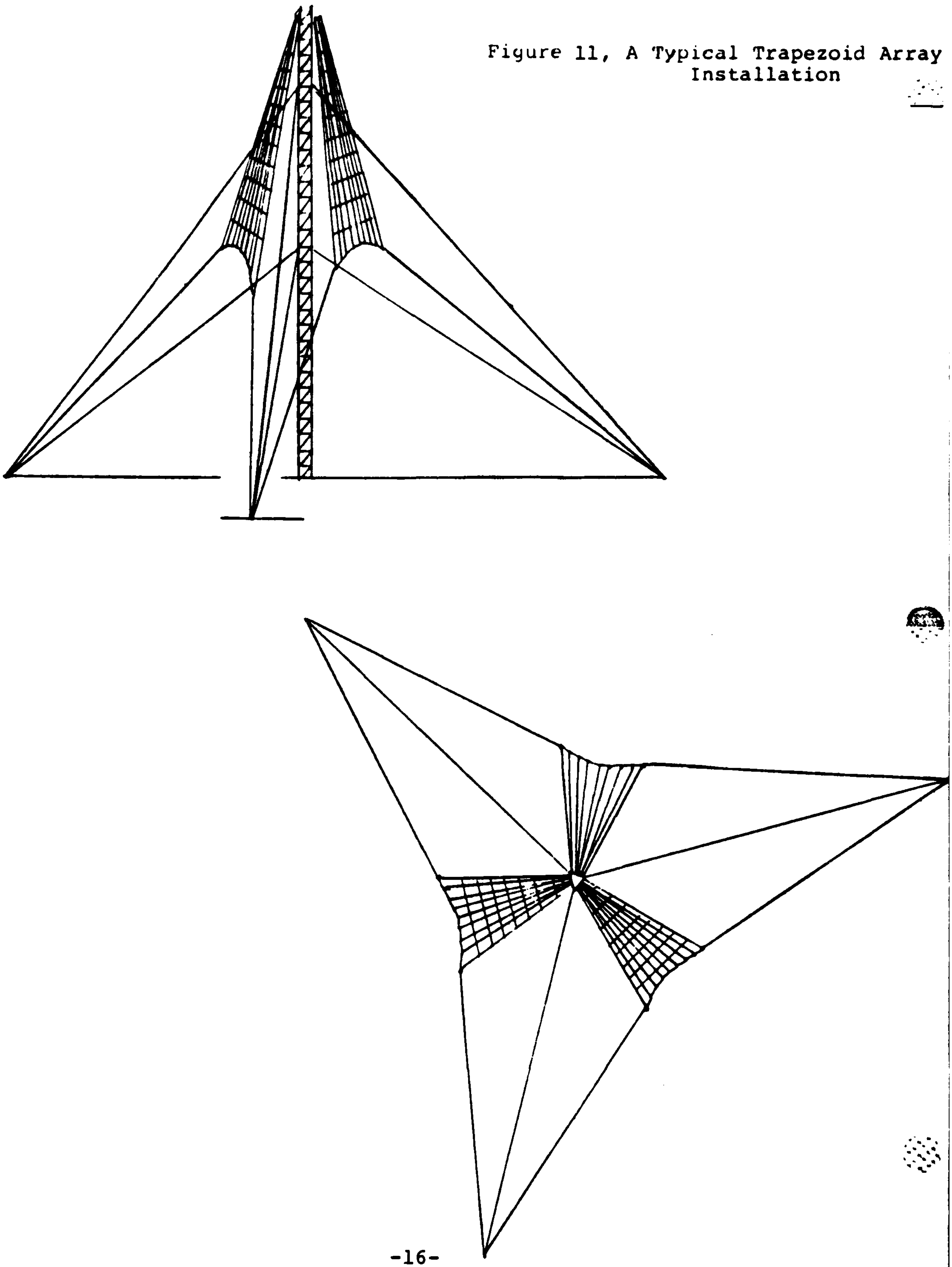


Figure 12, A Typical Conic Array Installation for Cone Roof Storage Tanks

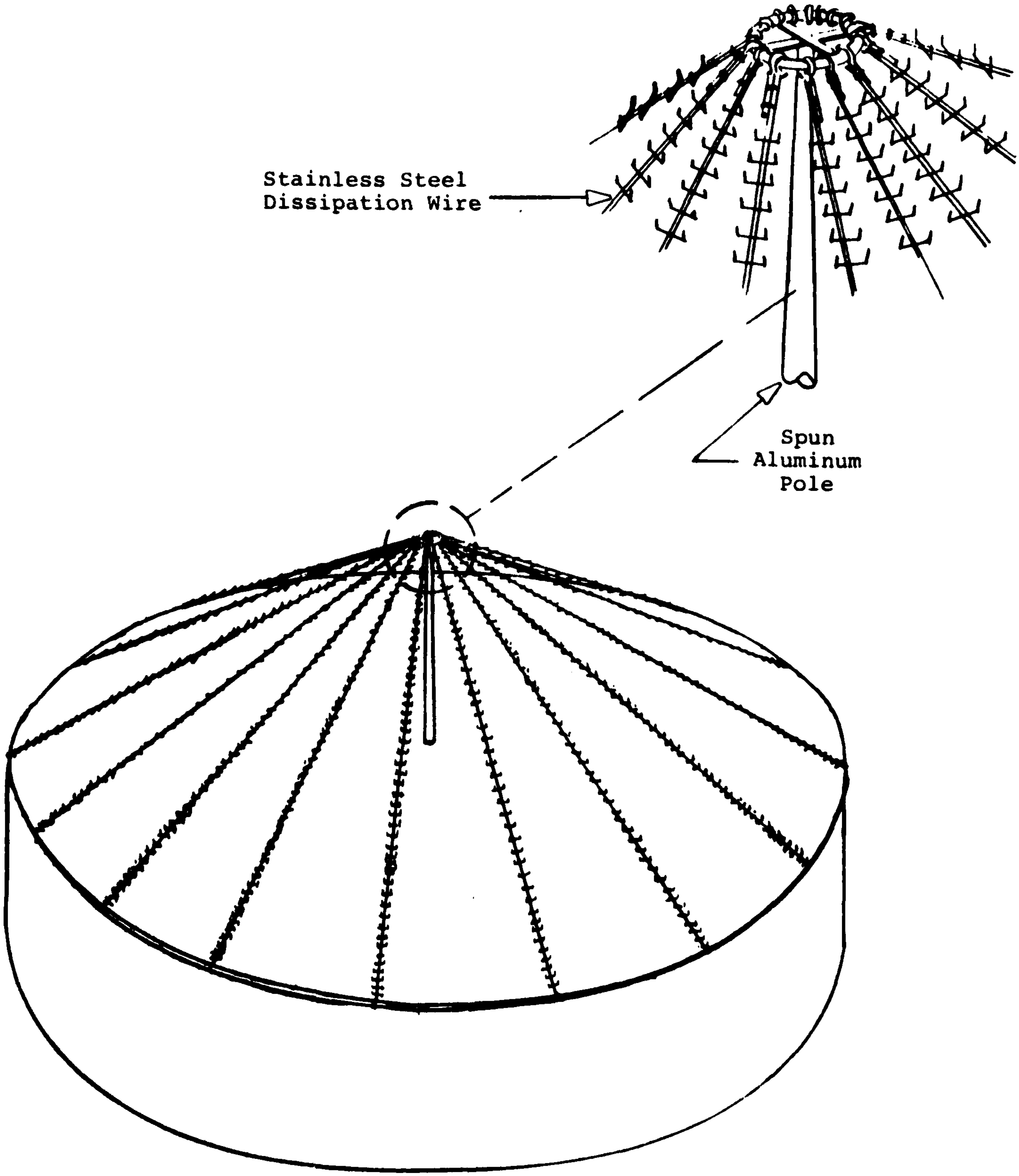
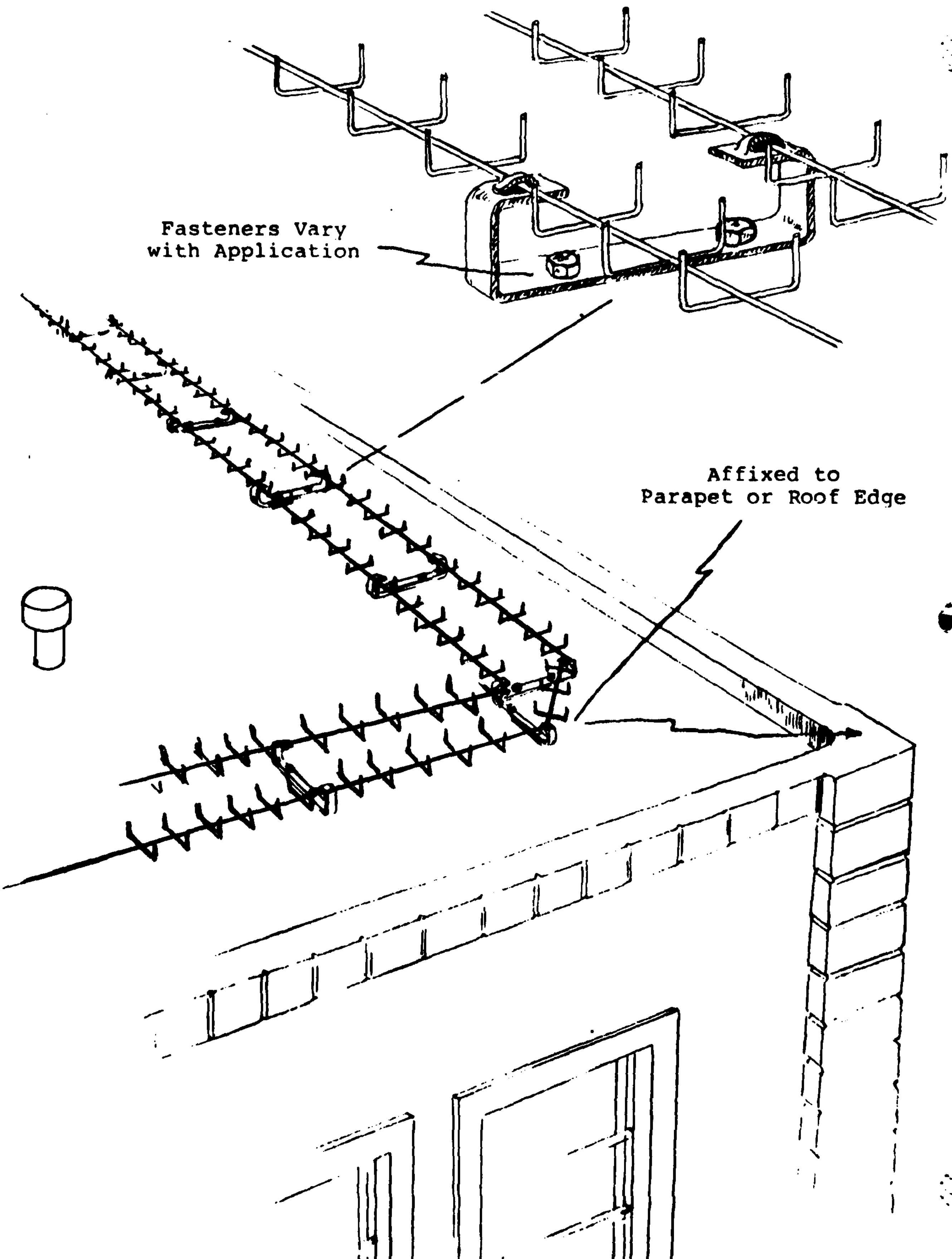


FIGURE 13, ROOF ARRAY CONCEPT



RELIABILITY CONSIDERATIONS

Recorded Data

Dissipator current flow measurements have varied from a few microamperes to nearly half an ampere per Array. Measurements have been made on a single point and on multiple point diss'pators by a number of researchers and agencies. The assumption has been made that large current flows are required to prevent a lightning strike. This assumption is in turn based on the premise that at least 30 coulombs must be dealt with within a period of about 30 seconds or so.[8] This is true if the dissipator is to deal with the whole charge. However, it must be evident that it is not necessary to prevent all lightning in order to prevent a strike to a given area. It is also evident that the latter objective would require far less current flow. Unfortunately, the exact value cannot be derived empirically, but it is evident that a large current flow would only be required when and if a stroke would otherwise be formed between the area of concern and the storm cells. Performance data should confirm or reject this.

Current measurements have been made using operating Array Systems. The current levels recorded have all been significantly lower than expected for the given set of conditions. These data have been recorded by USAF, NASA, Florida Power Corporation, LEA,Inc. personnel and some others. Most of the personnel making these recordings are considered both competent and reliable. All data, except possibly the MILA Report, are considered reliable (some of the data used in the MILA Report is considered suspect).

Figure 14 represents a segment of an actual recording taken by USAF contract personnel from an Array on a 1200 foot tower in the Florida panhandle. Current flows were recorded for long periods of time at 2200 microamperes. The recording was taken during a period when an active storm was in the area. The large spikes were nearby discharges; the small ones were at some distance.

Figure 15 presents a segment of an actual recording taken by NASA from a small Array mounted on a 60 foot utility pole. The peak current flow recorded was approximately 500 microamperes at a time when the storm was directly overhead. The transients are also related to momentary changes in the field due to local and remote lightning activity.

Figure 16 presents a segment from an actual recording make by personnel of Florida Power Corporation. The recording was taken from an old model unbrella Array mounted on a 100 foot tower located in Orlando, Florida. The maximum steady current recorded on that site on this tape was over 300 microamperes. Because of the slow speed of the recorder much of the details and higher current levels are lost in the blur of ink.

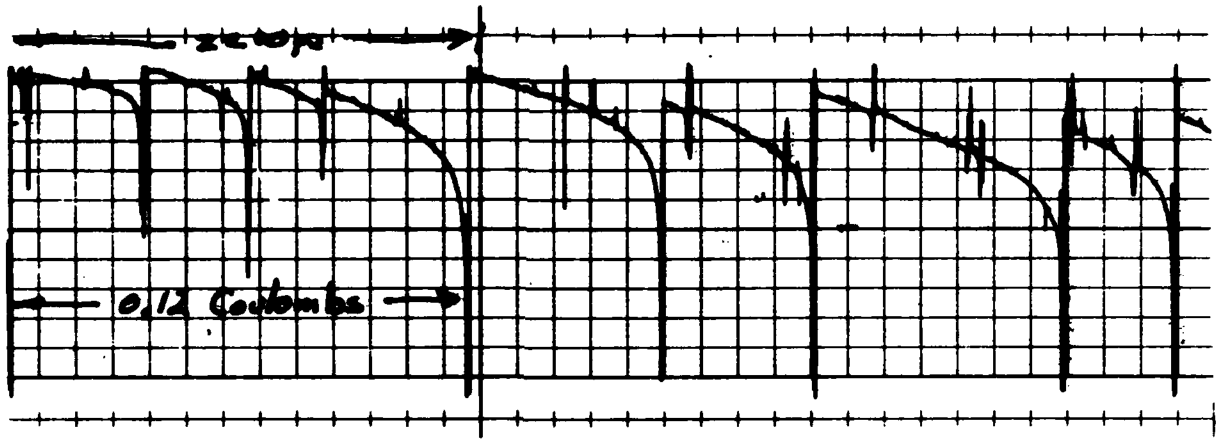


FIGURE 14, DISSIPATION CURRENT, ARRAY ON A 330 METER TOWER IN NORTHERN FLORIDA

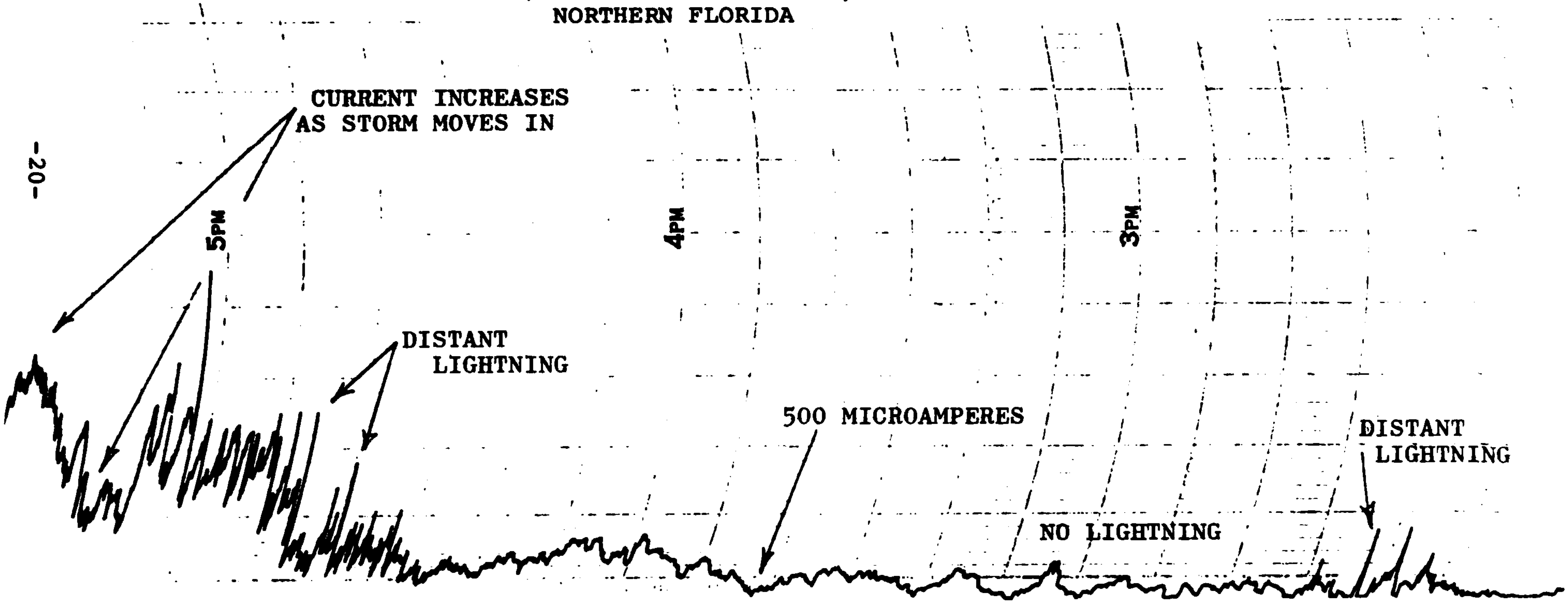


Figure 15, Dissipation Current, small Array on 20 meter pole, NASA Station

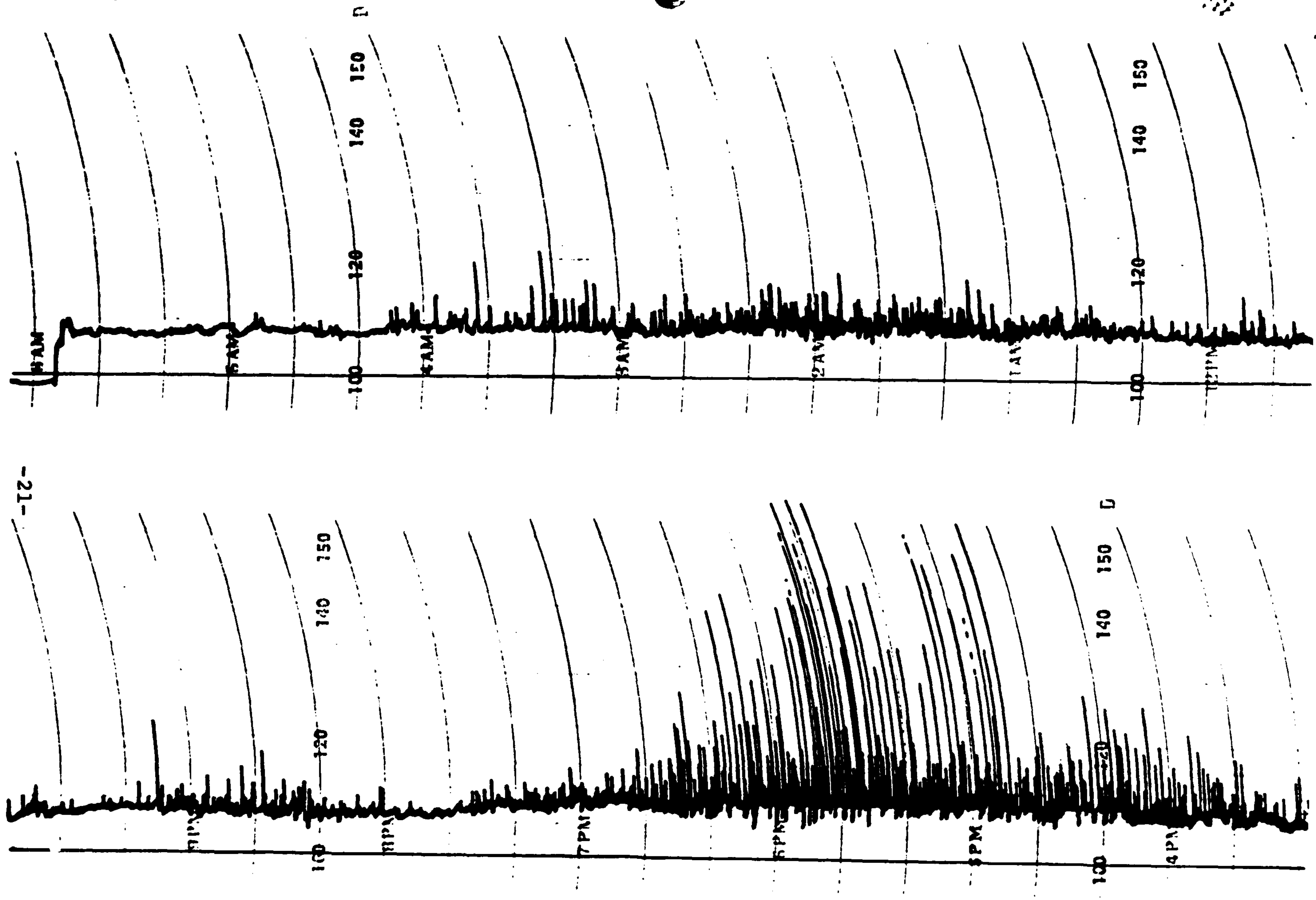


FIGURE 16, DISSIPATION CURRENT, ARRAY ON 30 METER TOWER, CENTRAL FLORIDA

Other data taken by Florida Power and Light personnel, other electric power company personnel and others indicate current flows of from a few microamperes when a storm is on one side to 500 or more when the storm is nearby or overhead and the Array is on a tower of less than 100 meters.

Observed Data

Pertinent on-site observations have taken two forms: that seen by observers and that recorded by camera. Several people on the site where an Array was installed have reported seeing some peculiar phenomena:

On a NASA Station in North Carolina and at the Federal Express Facility in Memphis observers reported seeing the Arrays momentarily glow during a stormy night when there was lightning nearby and the storm was overhead.

On a Florida Power Corporation site in central Florida technicians were working in the area during an intense storm in the late afternoon. Several of the technicians reported seeing a lightning bolt come to within several hundred feet of the Array and make a short right angle turn striking a nearby structure of much lower elevation.

In May of 1975 a storm was in progress over a 1200 foot tower with an LEA Array installed. A video camera was focused on the Array and a picture was recorded at 12:55 PM of what was termed "an interesting event". A reproduction of that picture is presented in Figure 17. The observer stated that "at the time of a lightning stroke some distance beyond the tower a spark of maybe 100 or 200 feet was seen to leave the Array. This spark did not meet a downward leader and did not progress to become an upward leader". A study of the photo reveals that the phenomenon was not a spark but what has been termed St. Elmo's Fire, corona or ion plasma.

Performance Data

Performance data is significant since it is the real indicator of the DAS value. Performance data in this case is of the go-no-go type, that is, strikes or no strikes. The most valuable data of this type is where there was a good prior history (many strikes) and then none after installation of the LEA Array System. The longer the past installation period the better. The following are some pertinent data samples:

Communications Site C-9, Eglin AFB, Florida was made up of a 366 meter tower supporting two UHF communications antennas and some meteorology equipment. The site is very remote, on the highest land in Florida. The isokeraunic level is about 88. According to an accepted method of estimating the strike hazard this site should be struck an average of 122 times a year. Observers on site stated that the tower had been struck repeatedly during every storm.

In May of 1973 LEA installed a prototype Dissipation Array System as illustrated by Figure 18. The site was instrumented and monitored by USAF contractor personnel for about 15 months. No strikes were recorded for a period of 22 months, but there was some damage noted due to power line surges. Dissipation currents of up to 150 milliamperes were recorded. This first Array was subsequently replaced by a second Array which later was found to be of inferior design. In spite of this, site history reveals that little damage can be traced to lightning activity, and most of that was related to power line surges.

Neither of the above Array Systems are now used for towers of that height. Even so, these old Arrays were proven deterrents to lightning strikes. The tower at the C-9 Site was destroyed by a hurricane in 1976.

Radio Station CKLW, Windsor, Ontario, Canada is a broadcast station located just off Lake Erie serving Windsor, Ontario. The antenna system is composed of five well grounded towers about 92 meters high. All broadcast stations have an extensive grounding system as a counterpoise with radials hundreds of feet long every three degrees. According to the station log this station averaged 25 outages per year due to lightning strikes to the towers. The isokeraunic level for this area is about 31.

In November of 1972 LEA installed disc-shaped Arrays as illustrated by Figure 19. These systems have been functioning since that time without any outages or known lightning strikes. At one time dissipation current measurements were made and current flows of up to 20 milliamperes were noted by the stations's chief engineer.

WBBH-TV, Ft. Myers, Florida is a television station serving that area of Florida. Its antenna is mounted on a tower with a total height of well over 300 meters. The isokeraunic level in that area is about 100. The tower or antenna had been struck an average of 48 times per year resulting in damage and loss of air time on many occasions. In 1975 LEA was asked to install a Dissipation Array. A Trapezoid Array was subsequently installed and no strikes or outages have been noted since that time.

KLAS-TV, Las Vegas, Nevada is of interest for two reasons: its high former strike record, and its site situation. It was off the air five or six times a year. Physically, there is a 28 meter antenna atop a 62 meter tower resting on a rock pile, no soil cover in the area. The stones had to be moved to set the GCC in place (there was virtually no grounding). Prior to the Array installation the station was off the air anytime there was lightning activity in the area. In 1974 LEA installed an early form of Trapezoid Array. The station has never been off the air due to lightning activity since that time.

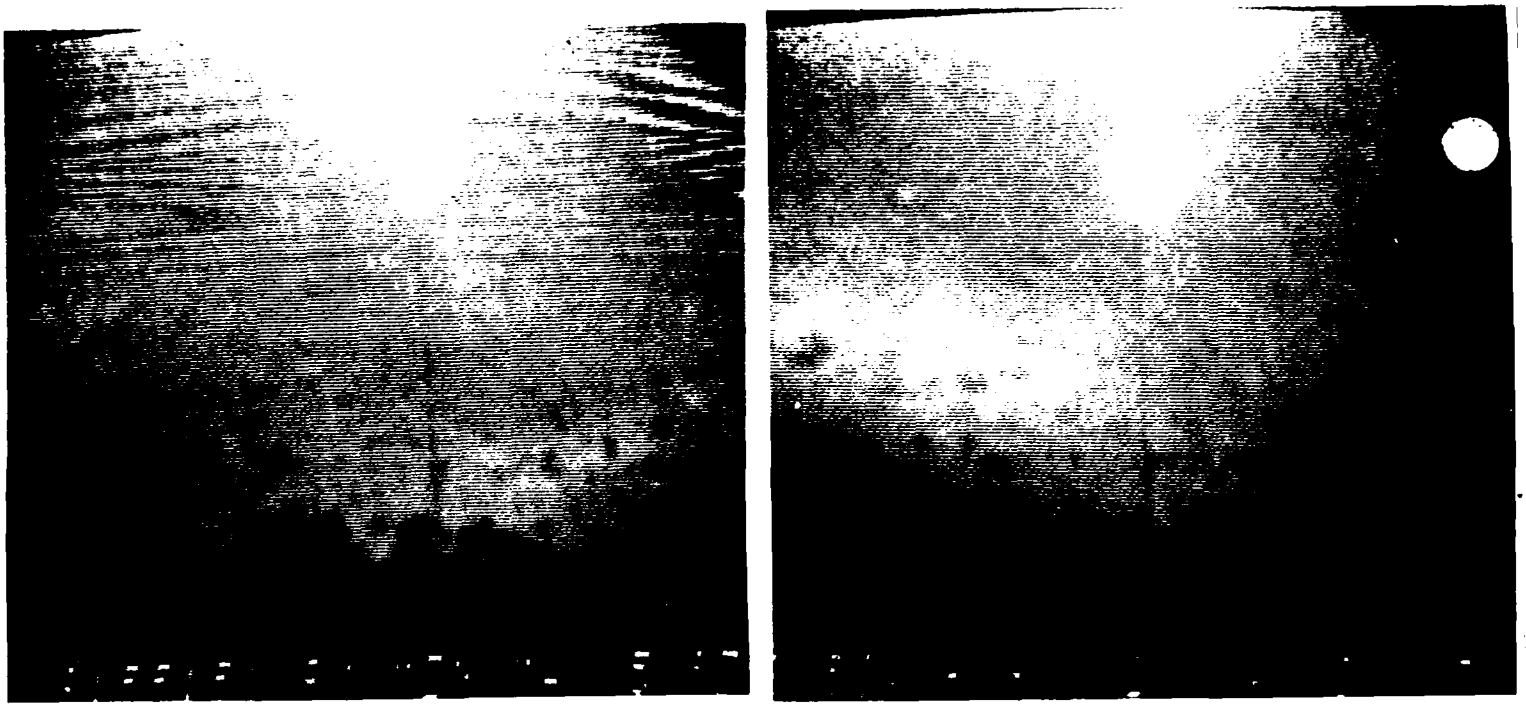


FIGURE 17, CORONA DISCHARGE FROM AN LEA ARRAY

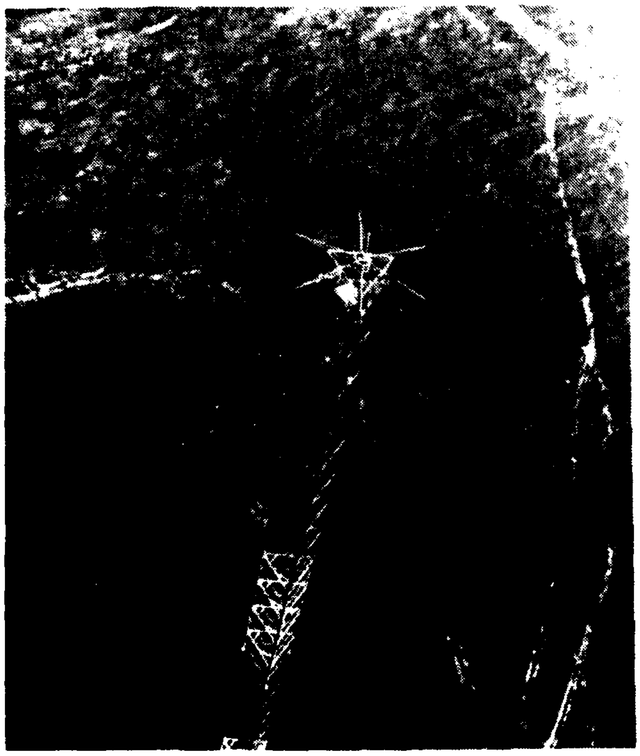


FIGURE 18, DISSIPATION ARRAY INSTALLATION AT EGLIN AFB

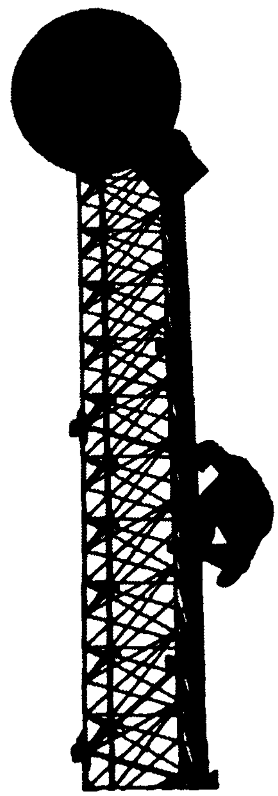


FIGURE 19, DISSIPATION ARRAY INSTALLATION AT CKLW, CANADA

Union Oil Facility, Santan, Indonesia, on the Island of Kalimantan (formerly Borneo). This facility is carved out of the jungle near the village of Santan just under the equator. The land is flat and on the eastern shores of the Makassar Straits. The best estimate for the isokeraunic level is about 260. These data, when used to estimate the probable number of strikes to the facility area, reveal a potential hazard rate of over 200 strikes per year. Union Oil elected to protect the area with the Dissipation Array System installed as the facility was being constructed. Work was completed in March of 1973 and there have been no lightning strikes to or near that area in almost ten years.

Florida Power Corporation Substation, Florida. Rio Pinar is the main switching station for the Florida Power Corporation's central Florida transmission and distributing system. Its early history was plagued with outages, often at times when the control capability was vital. Outages remained until a man could be dispatched to perform the switching operations manually.

The substation is about 800 feet long and about 400 feet wide. Near one end is located a 100 foot command and control tower. LEA mounted a large umbrella Array atop that tower, integrating both the substation ground mat and the control station mat into a Ground Current Collector subsystem. The installation was completed in November of 1974 and instrumented by Florida Power Corporation personnel. No strikes have been recorded or outages experienced since the installation was completed. Conversely, the dissipation current recordings taken were considered positive proof of the system's capability to prevent strikes.

Philadelphia Electric, Peachbottom Nuclear Plant is in central Pennsylvania on the Susquahanna River. The plant occupies nearly 100 acres in an area where the isokeraunic level is 40. The site is dominated by the off-gas stack which towers some 720 feet above the main plant. Estimates for the stroke hazard range from two to five times each year. Plant history reveals lightning strikes to the stack each year and related losses. LEA installed an Array System with three dissipators in 1976 to protect the whole plant. No strikes have been recorded since the installation was completed.

The Assurance Factor

LEA provides a guarantee with each DAS installation as assurance not insurance. LEA guarantees to make the system work. These are more than words as Dissipation Array history of installations will prove. Table 1 presents a summary of that history from late 1971 through 1982.

An analysis of Array performance history to date provides more than reasonable assurance as to DAS reliability. A reliability assessment requires statistics, i.e., performance history. To this end there are nearly a thousand Array Systems installed. Some of these have only one season's history, others have up to eleven years of history. The cumulative total history of reliable data has now reached nearly three thousand system-years. Of these only a few, less than 15, were reported to have failed to prevent a lightning strike. These were for the most part concentrated in the earlier years, three through five. Since that time only one or two have failed. In all cases the cause of the failure was specifically identified, and where possible, corrective action taken that subsequently prevented further strikes.

The statistics of Array performance permit a good estimate of Dissipation Array System reliability:

First, using the data as is and disregarding the fact that "failed systems" were corrected, system reliability is 0.9951.

Second, taking into account the impact of the retrofit work and resulting performance, the system reliability is in excess of 0.9992.

These reliability estimates provide positive assurance of the Dissipation Array System's reliability in an academic frame-of-reference. However, the spectacular testimonials from customers suffering from a long history of lightning losses and an immediate reduction to zero losses after the Array installation is perhaps more persuasive. This is particularly true when it is realized that some of these histories cover many years before the installation and a period of several years after the installation.

There is no reasonable doubt as to the effectiveness of the Dissipation Array in <u>preventing</u> the lightning strike. Any person, technical or non-technical, can review the data and reach that conclusion if they are intellectually honest with themselves and maintain an open mind.

There is an impressive list of references available covering just about any type of facility and risk potential. The list can be obtained from our office.

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TABLE 1

SUMMARY OF DISSIPATION ARRAY INSTALLATIONS

YEAR	CUSTOMER CLASSIFICATION	NO. OF SITES	FACILITY PROTECTED	NO. OF ARRAYS
1971	Television Stations	1	Transmitter and Antenna	1
1972	Telephone Company	1	Microwave Station	1
	Radio Station	1	Transmitter Site	5
1973	Oil Company	1	Storage and Processing Area	6
	Television Stations	2	Transmitter Sites	2
	CATV Company	1	Translator Site	1
	Broadcast Stations	1	AM Transmitter Site	1
	Power Company	1	Substation	1
	U.S.A.F.	1	1,200 Foot Communications Tower	1
	Mining Company	1	Power Distribution Line	3 Mi.
	NASA	1	Tracking Station	8
	Public Park	1	Parking Lot,	19
			Large Building	1
1974	AM Radio Stations	4	Transmitter Sites	15
	FM Radio Stations	2	Transmitter Sites	2
	Power Companies	7	Meteorology Sites	10
	NASA	1	Meteorology Site	1
1975	AM Radio Stations	8	Transmitter Sites	30
	Power Companies	2	Microwave Relay	1
		1	Meteorology Facilities	1
	Television Companies	2	Transmitter Sites	2
	CATV Company	1	Translator Site	1
	Oil Companies	3	Storage and Processing Area	12
	Industrial Plants	2	Plant Areas	12
		2	Meteorology Sites	8
		1	Power Distribution Lines	3 Mi.
		1	Explosives Handling Area	2
1976	Power Companies	5	Meteorology Sites	5
		1	Distribution Lines	2 Mi.
		2	Generating Plants	2
	Airport Authority	1	High Mast Lighting	19
	NASA	5	Tracking Stations	26
		1	Distribution Line	3.5 Mi.
		2	Meteorology Sites	2
	AM Radio Stations	2	Transmitter Sites	12
	FM Radio Stations	2	Transmitter Sites	2
	Private Party	1	Home	1

YEAR	CUSTOMER CLASSIFICATION	NO. OF SITES	FACILITY PROTECTED	NO. OF ARRAYS
1977	Industrial Plant	2	Plant Area	11
	Power Company	3	Meteorology Sites	3
		2	Communications Sites	2
		1	Generating Plant	4
		1	Substation	6
	CATV Companies	3	TV Translator Sites	10
	Oil Company	1	Compressor Area	1
	AM Radio Stations	3	Transmitter Sites	18
	University	1	Meteorology Site	1
	Hospital	1	Building and Tower	1
	U.S./D.O.T.	5	Communications Sites	20
	Japanese Power Company	3	Communications Sites	3
	Mexican TV Station	2	Transmitter Sites	2
		1	Distribution Line	5 Mi.
1978	Power Companies	5	Generating Stations	6
		2	Energy Control Center	3
		2	Substations	5
	Broadcast and TV	5	Transmitter Sites	16
	Communications Sites	2	Transmitter Sites	2
	Industrial Plants	5	Buildings	9
	Petroleum Companies	2	Refineries	13
		1	Reservoir	6
1979	Broadcast and TV	7	Transmitter Sites	7
	Communications Sites	4	Transceiver Sites	4
	French NASA	1	Launch Site	2
	Petrochemical Plant	1	Refinery	5
	U.S.C.G.	1	Loran Site	1
	Power Companies	1	Generating Station	1
	Military	1	Control and Training	1
1980	Broadcast and TV	5	Transmitter Sites	6
	Communications Sites	2	Transceiver Sites (Police)	2
	Industrial Facility	2	Building	2
	Petroleum Company	1	Storage Tanks	22
1981	Industrial Plants	1	Process Systems	5
		1	Mine Area	6
	Broadcast and TV	7	Transmitter Sites	8
	Public Utility	4	Generation Facility	1
			System Control Sites	3
	Federal Express	1 sq.Km	Airport Ramp Area, Buildings and Hangers	12

YEAR	CUSTOMER CLASSIFICATION	NO. OF SITES	FACILITY PROTECTED	NO. OF ARRAYS
1982	Broadcast and TV	4	Transmitter Sites	4
	Communications Sites	2	Earth Stations	2
	Industrial Plant	3	Weather Stations	5
		1	Process Area	4
	Petroleum Companies	3	Storage Facilities	5
	Airport	1	Ramp Facilities	2
	Public Utility	1	System Control Facility	1
	State Hospital	1	Area	1
	Military Site	1	Control Facility	1
	Federal Facility	1	Power Facility	1
1983	Broadcast and TV	2	Transmitter Sites	2
	State Hospital	1	Area	1
	Industrial Chemical	7	Chemical Plant Facility	6
	Petroleum Companies	15	Water Injection Facility	18
		1	Separation Station	1
		1	Microwave Link-Off Shore Op.	1
	Public Utility	2	Communication & Data Systems	2
	Federal Express	1	Airport Hanger Facility DC-10	1
		1	Fuel Farm Area	1
		1	Loading & Unloading Facility	1
	Environmental	1	Meteorological Facility	1
			TOTAL ARRAYS INSTALLED	509

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